AIDA: Asteroid Impact & Deflection Assessment – A Joint ESA-NASA Mission

Chelyabinsk Meteor on 15 February 2013

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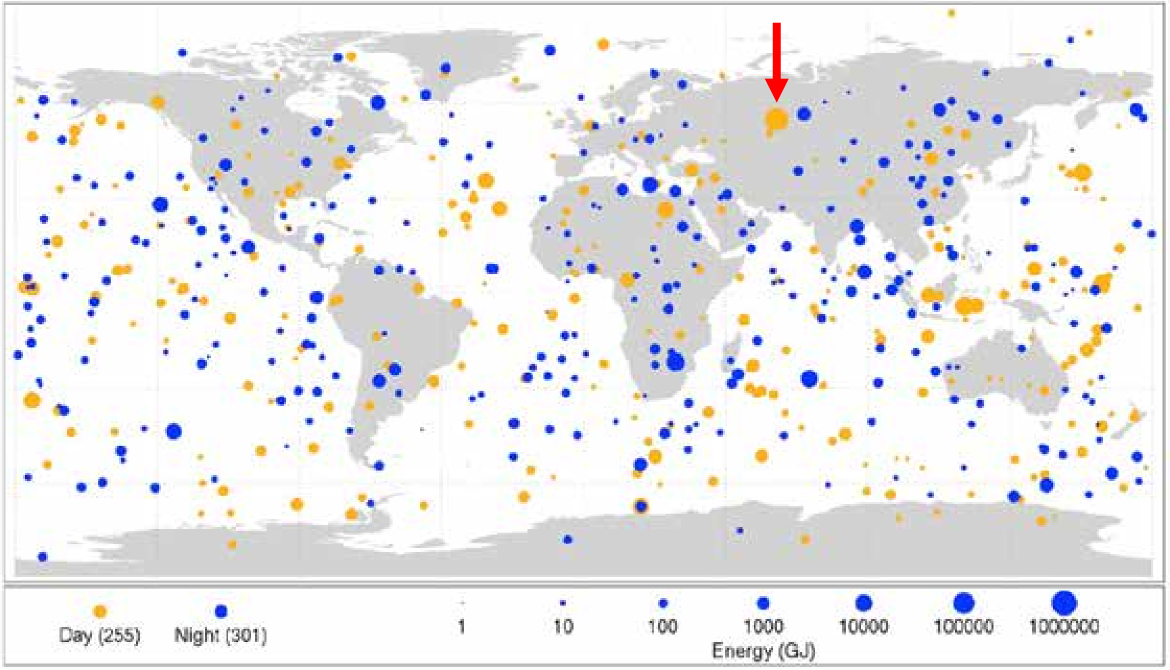
On behalf of the Joint NASA – ESA AIDA Team

FISO Telecon 4-29-2015

Planetary Defense: Asteroid Mitigation

Small asteroids that hit the Earth, 1994-2013



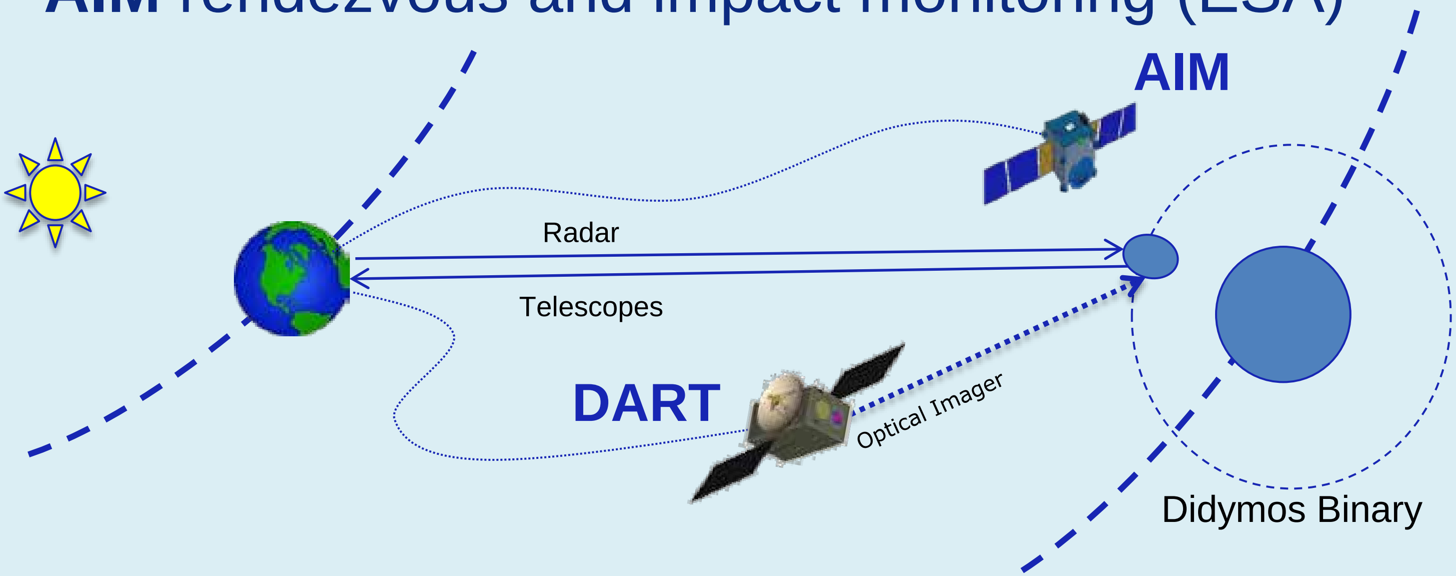
Mitigation Techniques:

- Ø **Kinetic Impactor**
- Energetic Explosion
- Gravity Tractor
- Directed Energy

Chelyabinsk-sized impacts (500 kilotons TNT) every few decades
Tunguska-sized impacts (5 megatons TNT) every few centuries

AIDA: Full Scale Test of Asteroid Deflection

- **AIDA** international cooperation
  - First test of asteroid deflection by spacecraft kinetic impact
- **DART** kinetic impactor (NASA)
- **AIM** rendezvous and impact monitoring (ESA)

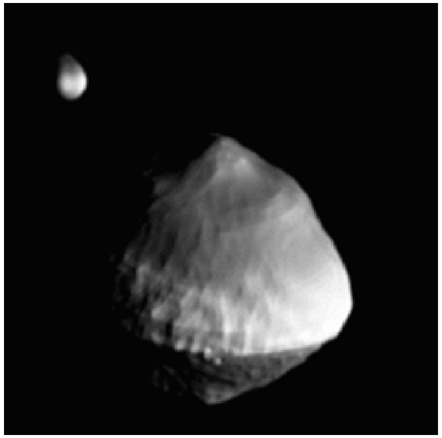


Goals: demonstrate the **ability to modify the orbital path of the secondary asteroid** of the 65803 Didymos binary system and **obtain scientific and technical results** that can be applied to other targets and missions.

AIDA

AIDA = AIM + DART

Target: Didymos in 2022



- ESA AIM rendezvous spacecraft

  Orbiter payload to characterize Didymos dynamical system and study impact results

  Asteroid proximity operations, lander release on secondary asteroid, deep-interior analysis

  Deep-space optical communication demonstration

- NASA DART interceptor and Earth-based observing

  Measure asteroid deflection to within 10%

  Return high resolution images of target prior to impact

  Autonomous guidance with proportional navigation to hit center of 150 meter target body

  Leverage space-based missile technology

AIDA = AIM + DART

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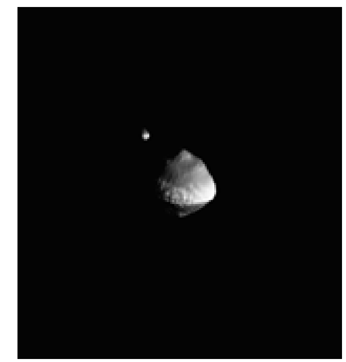
1st goal: Redirect secondary component of Didymos, and measure the deflection by monitoring the binary´s orbital period change

2nd goal: Measure all **scientific and technical** parameters allowing to interpret the deflection and extrapolate results to future missions or

AIM: Physical characterization by close-approach & lander

DART: Deflection by kinetic impact



Dual test validation by AIM spacecraft + ground-based optical/radar facilities

Both mission are independent but results boosted if flown together

Impact date (October 2022) and target (Didymos) are fixed.

AIDA is relevant for many disciplines

Planetary Defense
Deflection demonstration and characterization
Orbital state
Rotation state
Size, shape, gravity
Geology, surface properties
Density, internal structure
Sub-surface properties
Composition (mineral, chemical)

Science
Orbital state
Rotation state
Size, shape, gravity
Geology, surface properties
Density, internal structure
Sub-surface properties
Composition (including isotopic)

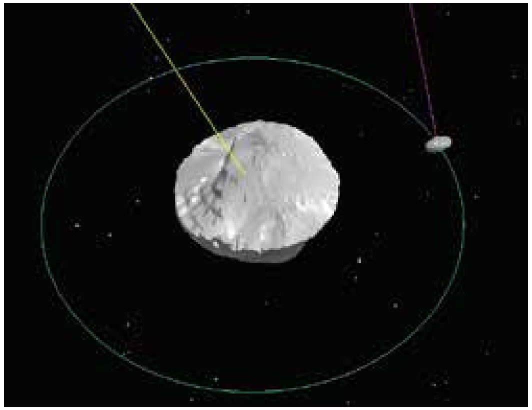
AIM-DART
Deflection demonstration and characterization
Orbital state
Rotation state
Size, shape, gravity
Geology, surface properties
Density, internal structure
Sub-surface properties

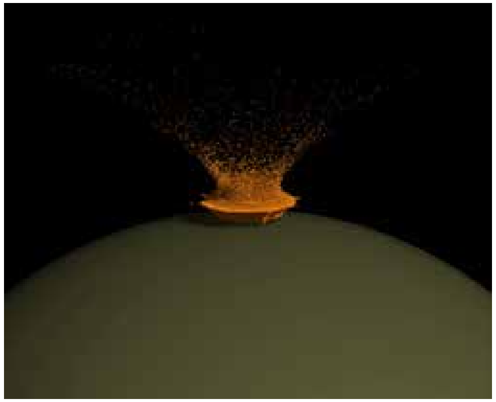
Human Exploration
Orbital state
Rotation state
Size, shape, gravity
Geology, surface properties
Density, internal structure
Composition (mineral, chemical)
Radiation environment
Dust environment

Resource Utilization
Geology, surface properties
Density, internal structure
Sub-surface properties
Composition (mineral, chemical)

AIDA "firsts"

First mission to **study a binary asteroid,** its **origins** and sound the **interior structure**





Jutzi & Michel 2014. Icarus
Schwartz & Michel, ASR, submitted

First mission to **measure asteroid deflection** by determining the "ejecta momentum amplification factor" of a kinetic impactor **as well as the initial conditions** (impact conditions, target's properties)

First mission to demonstrate **interplanetary optical communication** and **deep-space inter-satellite links with CubeSats** and a **lander** in deep-space.

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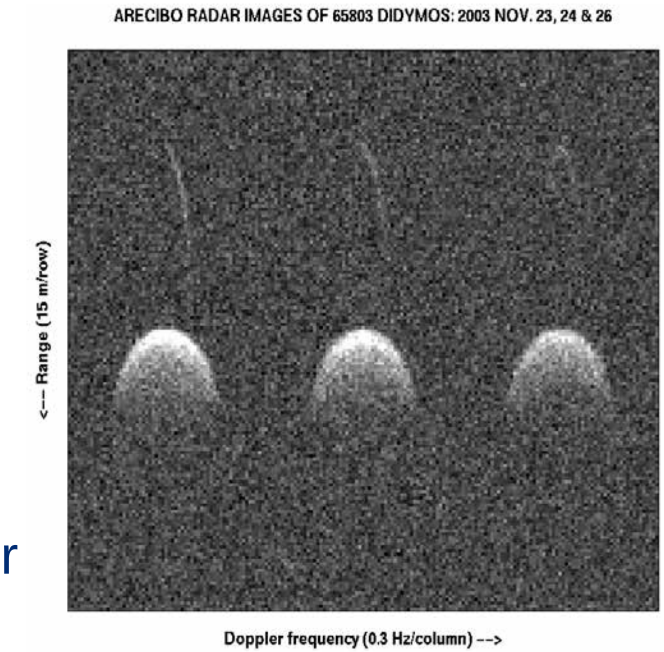
AIDA Target Properties

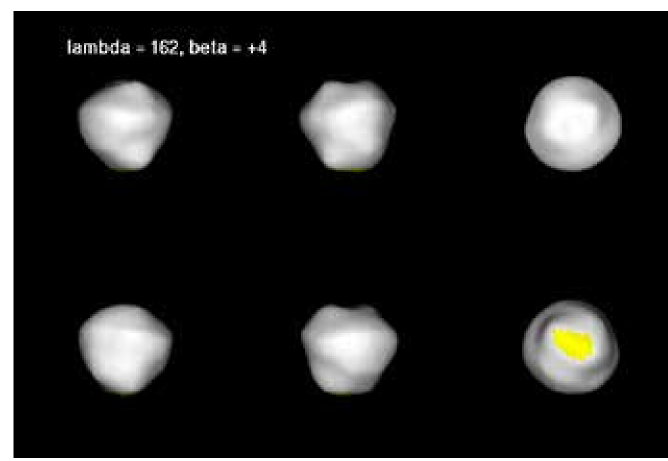
- **Discovered in April 1996**

- **S-type Near Earth Asteroid**
  - Perihelion distance 1.01 AU
  - Aphelion distance 2.3 AU
  - Close approach to Earth in Oct 2022
  - 0.07 AU range provides opportunity for ground observation of impact event

- **YORP spin-up binary system**
  - 800 m primary (rotation period 2.26 hr)
  - 170 m secondary (synchronous?)
  - Secondary in 11.9-hr orbit
  - Distance between primary's and secondary's centers: 1.1 km



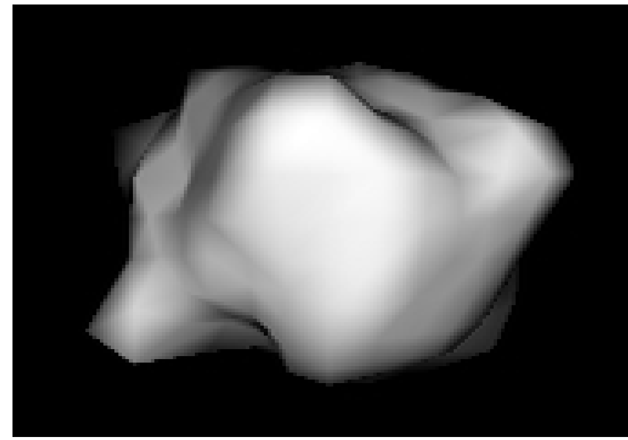
Radar image of Didymos, Nov. 2003



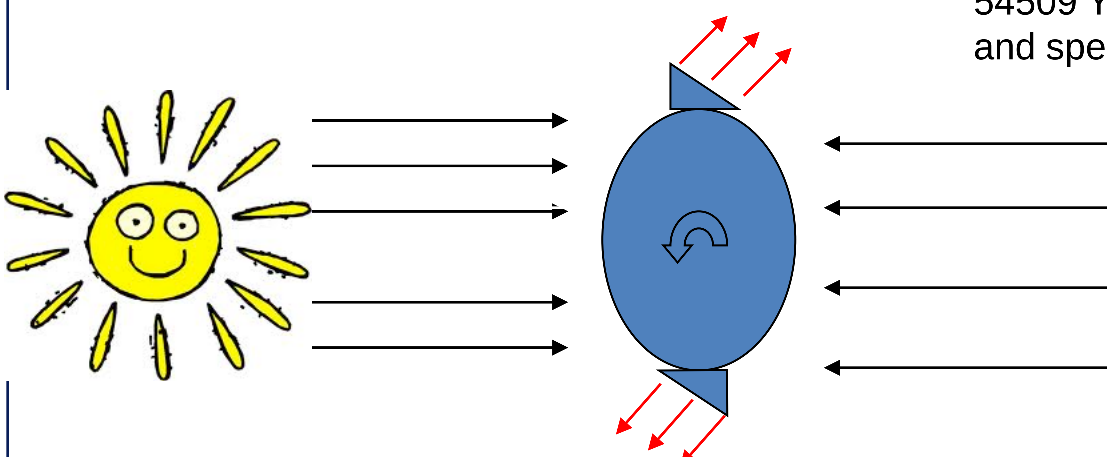
Binary formation: spin-up of an aggregate by YORP

- **Even sunlight, such as the "YORP" effect, can spin-up and disrupt asteroids.**
- Depends on body size distance from Sun.
- Spin-up timescale ~Myr.

Taylor et al. (2007)



54509 YORP: 12.2-minute rotation and speeding up!



Not all internal structures lead to a binary

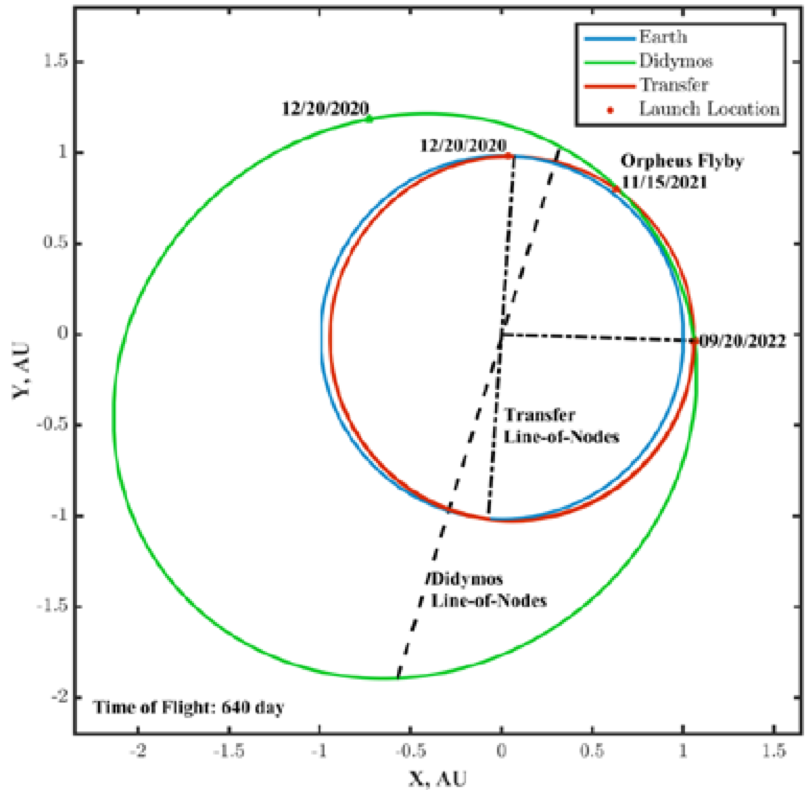
DART Objectives

$$\beta = \frac{transferred\ momentum}{incident\ momentum}$$

	Objectives	Measurements and Analyses
Planetary Defense	Demonstrate the spacecraft kinetic impact mitigation technique	Target an asteroid large enough to qualify as a PHA (larger than 100 m)
	Measure asteroid deflection	Target Didymos binary system; measure the binary period change to within 10% by Earth-based optical and radar observations
	Learn how to mitigate an asteroid by kinetic impact: validate models for momentum transfer in asteroid impacts	Determine energy transfer; infer β; determine crater size and ejecta distributions [with AIM] and constrain cratering models
Science and Exploration	Understand asteroid collision effects to infer physical properties of asteroid surface and subsurface	Light curve and radar observations of the binary for sizes and density; infer density, porosity, strength from cratering and from β [with AIM]
	Study long-term dynamics of DART impact ejecta	Observe and model transient disk and debris tail formation and evolution

2022 Didymos Intercept

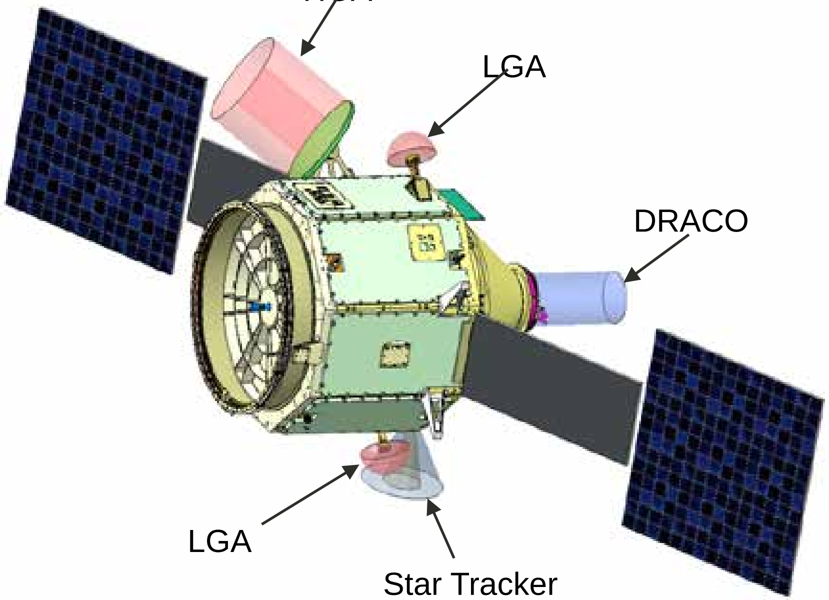
- DART trajectory remains near 1 AU from Sun, Earth distance < 0.20 AU.
- DART launch energy 5.7 km^2/s^2
- Impact velocity 6.5 km/s
- Impact event in Sept-Oct, 2022 occurs under excellent Earth-based viewing conditions including radar
- NEA flyby 10 months before Didymos encounter



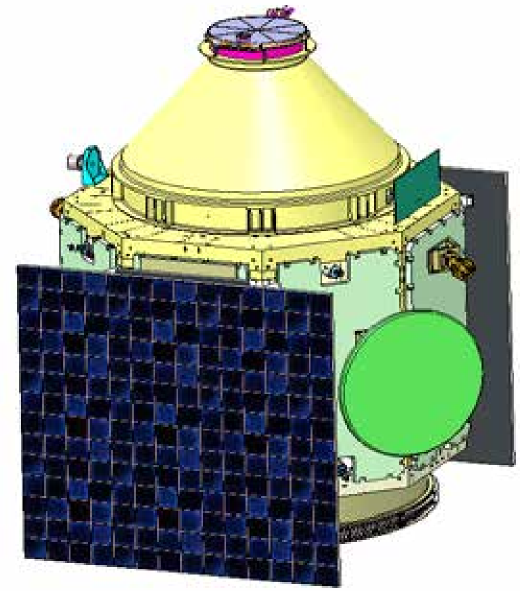
DART launches in Dec 2020 and intercepts Didymos on Sept 20, 2022

DART Vehicle

Orbit Configuration



Launch Configuration



- Three-axis stabilized, thruster control only
- Monoprop propulsion
- Single payload instrument: long focal length imager

Didymos Encounter Overview

Simple concept of operations

- Spacecraft designed for encounter geometry

DRACO on target, arrays on sun, HGA on Earth

Steerable HGA

Fixed solar arrays

- OpNav campaign hands off to SmartNav at 12-hr to go

15 km 1-sigma at hand off

Resolves secondary at ~2-4 hr to go

Targets center of primary until secondary resolved

- Thruster geometry supports pure translation &/or attitude adjustments
- Translation corrections frozen 2 min to go
- Meet resolution goal for returned imagery no later than 10 s to go

Deflection of Didymoon by DART Impact

- Period change of 0.17% corresponds to a ~73 s change in the period of the secondary
- Only momentum transferred along orbit velocity vector contributes to period change
- Relatively small mass required to achieve required deflection for a range of orbital phasing at arrival

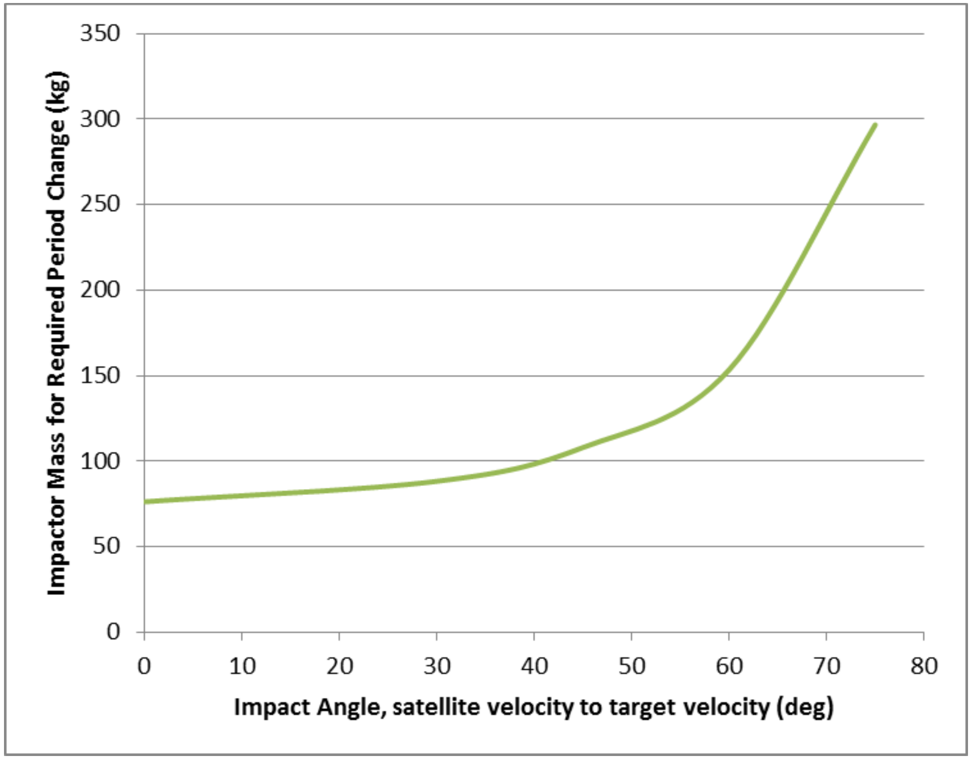


Chart assumes $\beta = 1$

DART Impact Results

Understanding and modeling the DART impact

Parameter b is defined as momentum change divided by momentum input

- **If no ejecta, then *b* = 1**
- **Ejecta *enhances* momentum transfer, *b* > 1**

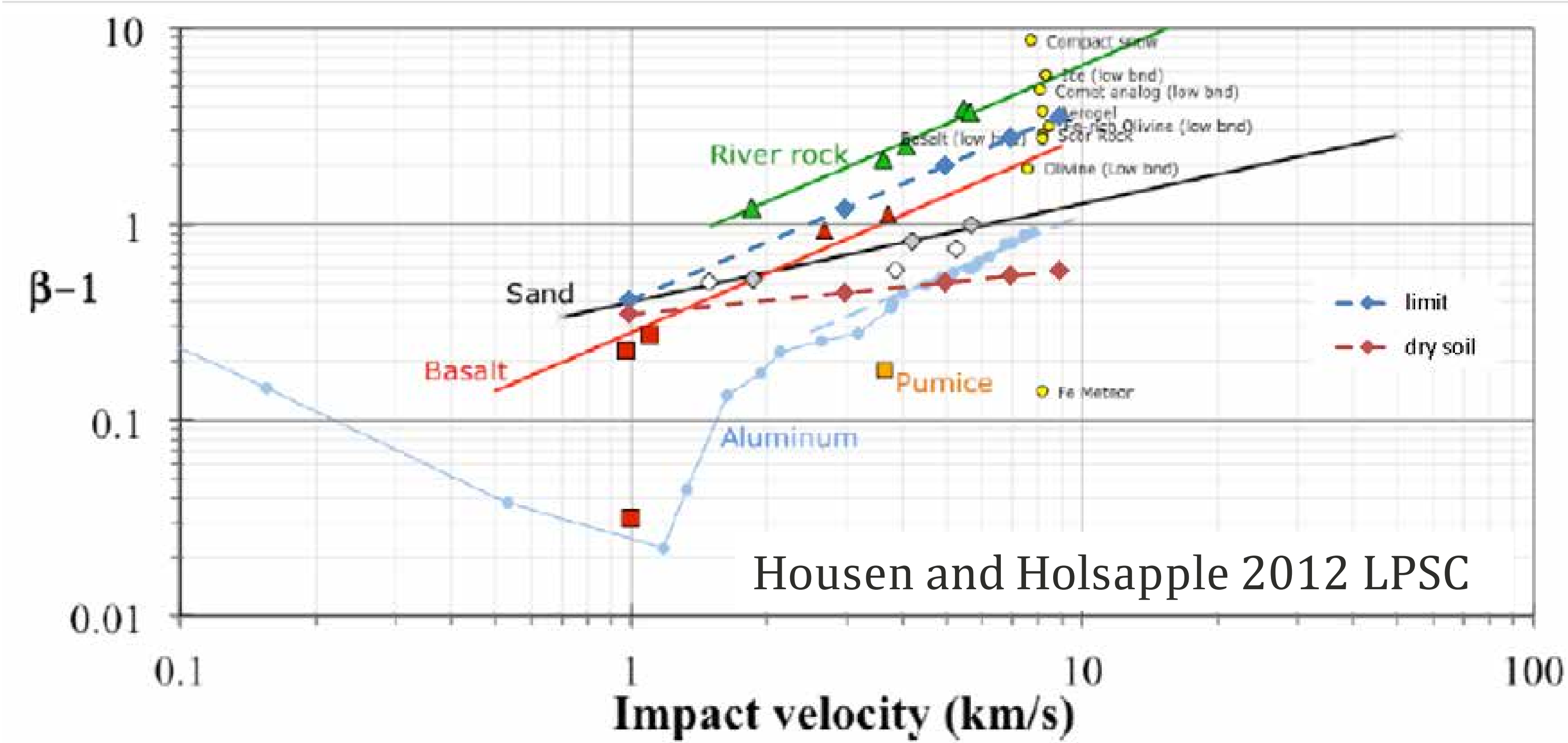
$$M \Delta V = \beta M_i V_i$$

M is target mass, ΔV is velocity change

The momentum transferred is *b* times the incident momentum, where *b* depends on the incident velocity and momentum, on target size and target material properties such as strength and porosity

Velocity Scaling of β from Lab Data and Scaling Laws

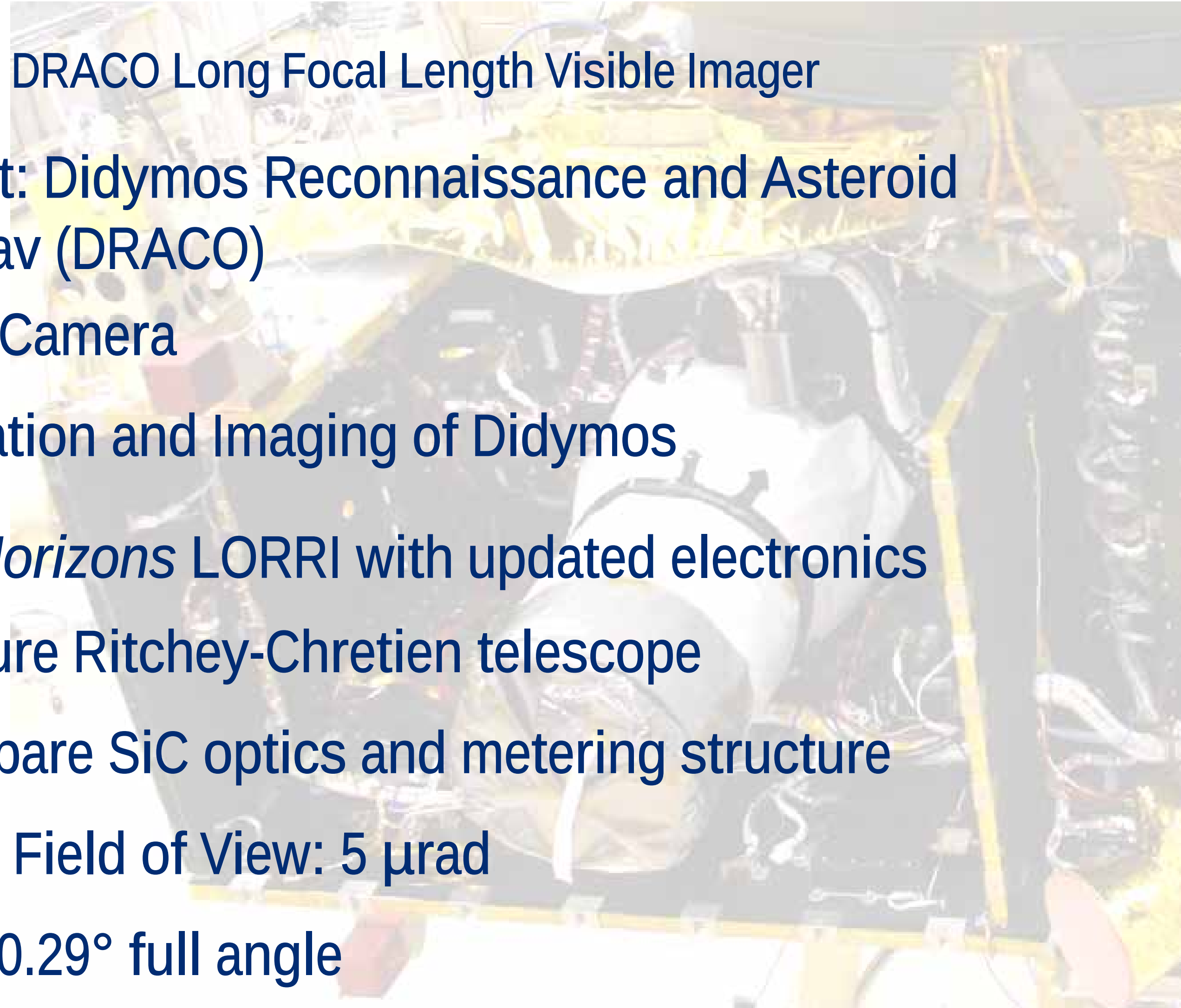
The DART impact is at 6.5 km/s.



Blue dashes, scaling law model with μ= 0.66, K= 0.12, Y= 18 MPa
Red dashes, scaling law model with μ= 0.41, K= 0.132, Y= 0.18 MPa
Scaling law models assume 300 kg DART impacts

DART Payload Instrument

DRACO Long Focal Length Visible Imager



- Single Instrument: Didymos Reconnaissance and Asteroid Camera for Op-nav (DRACO)
  - Narrow Angle Camera
  - Optical Navigation and Imaging of Didymos
- Rebuild of *New Horizons* LORRI with updated electronics
  - 203 mm aperture Ritchey-Chretien telescope
  - Use of flight spare SiC optics and metering structure
  - Instantaneous Field of View: 5 µrad
  - Field of View: 0.29° full angle

Binary Period from Light Curve Observations

Observe Mutual Events of Didymos

- Binaries often discovered by light curve observations
- Large telescopes not needed

  Magdalena Ridge 2.4-m (Ryan)

  Ondrejov 0.65-m (Pravec)

  Palmer Divide 0.5-m (Warner)
- Mutual event observations constrain sizes, rotation rate, and binary orbit
- Some ambiguities remain!

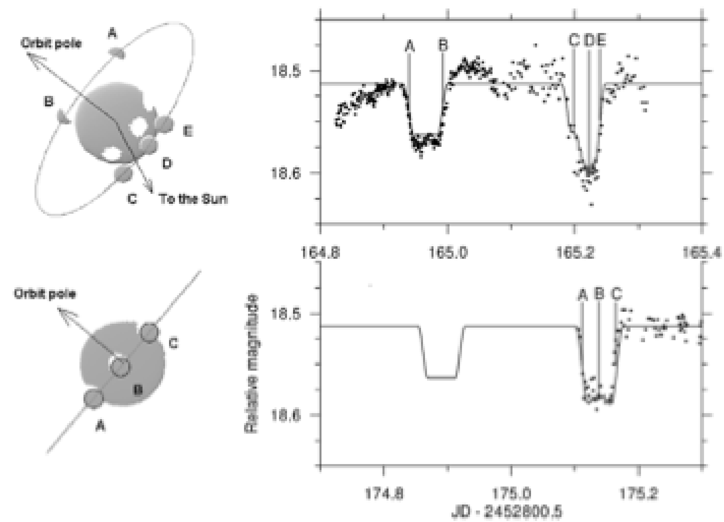


Fig. 4. The model of the system of (65803) Didymos as seen from Earth on 2003-11-22.0 and 2003-12-2.2. There are plotted the observational data (points) as well as the best-fit synthetic lightcurve of the prograde solution (curve). The other, mirror solution (retrograde) gives a nearly identical curve. The letters A to E denote particular positions of the secondary in its orbit and corresponding phases in the lightcurve. In this figure, the minima are shown in an order opposite to Fig. 1. Outside the minima, there is apparent a lightcurve variation caused by the secondary rotation that we did not model numerically.

Low obliquity, retrograde solution is more typical of YORP

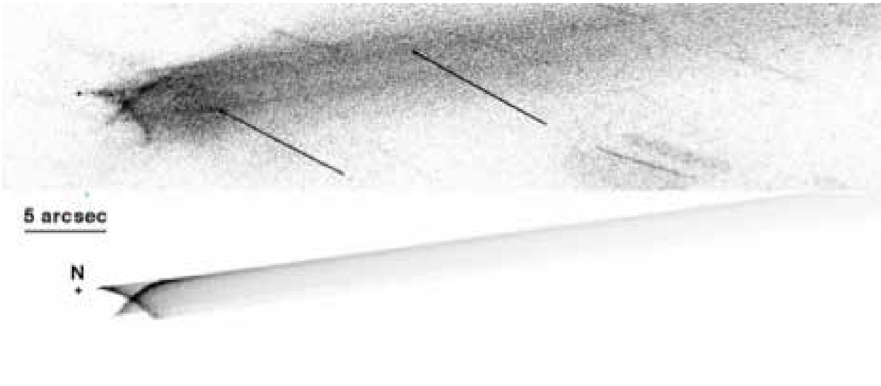
Post-Impact Observing Prospects

Observation and Modeling of DART ejecta

- Didymos and Didymoon are separated by up to 0.02 arcsec when 0.08 AU from Earth

  Marginally resolvable with ALMA (sub-mm), Magellan adaptive optics

- Observe and model post-disruption dust evolution, as done with active asteroids



Dust mode for disrupting asteroid P/2010 A2, Agarwal et al. (2013): Object is ~200 m across,
observed 1 AU from Earth. HST image (top) vs. model (bottom)

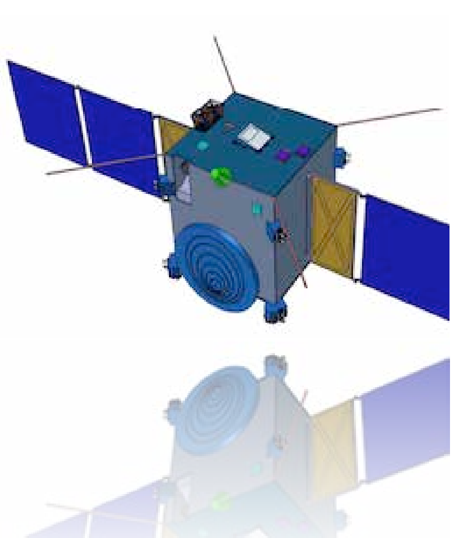
Asteroid Impact Mission (AIM)

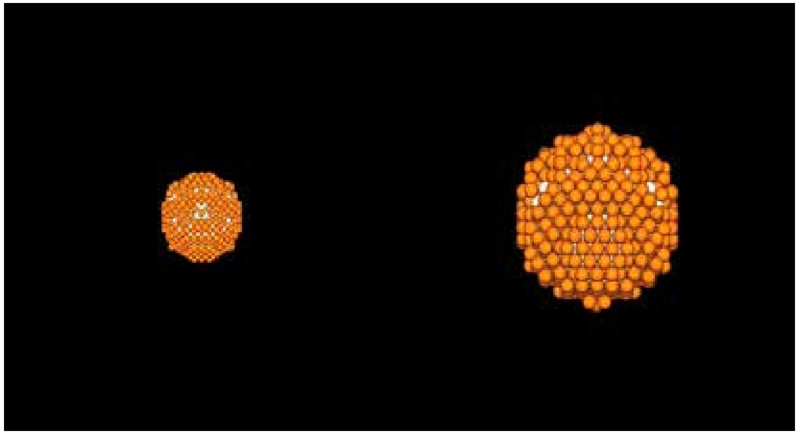
Small mission of opportunity to explore and demonstrate technologies for future missions while performing asteroid scientific investigations and addressing planetary defense

Technology demonstration

Asteroid impact mitigation

Science





Walsh, Richardson, Michel, 2008. Nature

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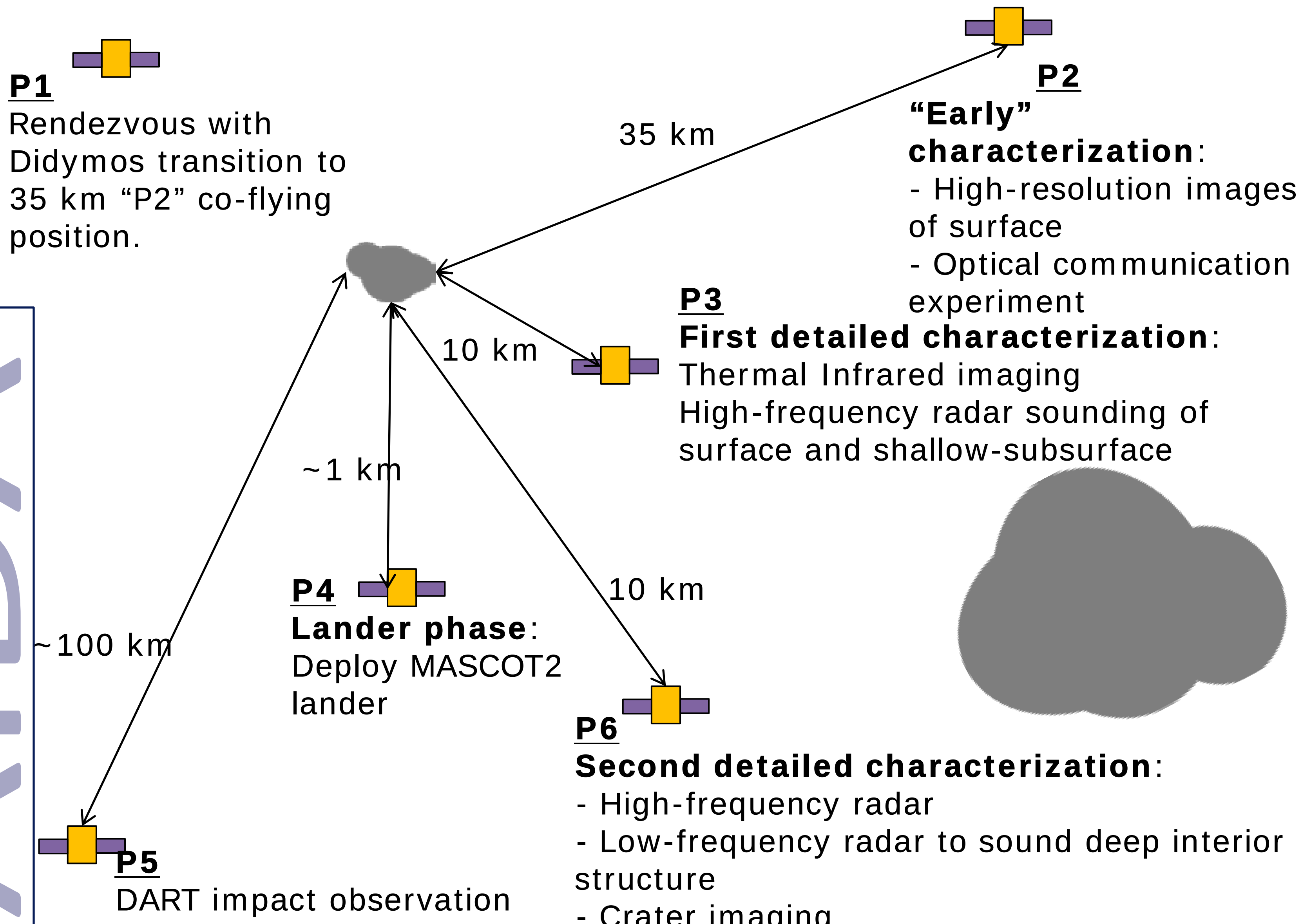
Close proximity Asteroid Operations: 29 May 2022 – 25 December 2022



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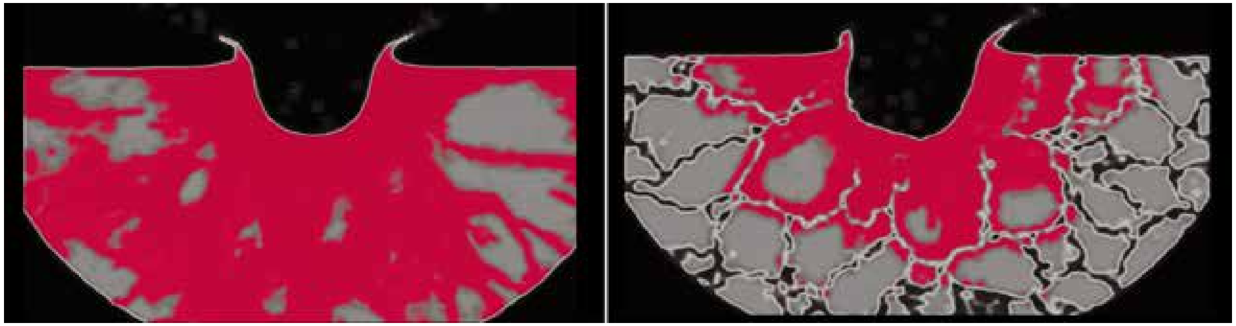
AIM main objectives related to mitigation

- First mission to measure properties that help to interpret an impact (DART) and inform mitigation:
  - Target's mass and shape
  - Dynamical state of the target (before/after impact)
  - Surface and subsurface properties (those that influence the most the impact response and momentum transfer efficiency)
  - Deep interior properties (may also influence the momentum transfer efficiency)



Jutzi & Michel 2014

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AIM main scientific objectives

- **Mass, surface and internal properties of the secondary of a binary system (first time)**
  - Implications for the collisional history of the Solar System
  - Implications for **binary formation scenarios** (15% of small NEAs are binaries)
- **Response of the surface** to an external solicitation (lander, impact) with detailed knowledge of surface properties
- **Dynamical properties and evolution** of a binary system (YORP, BYORP)
- **Ground truth:** link thermal inertia to actual surface properties

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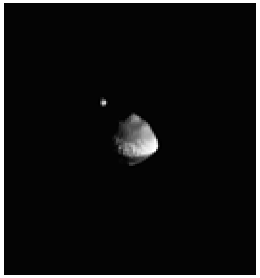
AIDA = AIM + DART

AIDA

- **ESA AIM rendezvous spacecraft**
  - Orbiter payload to characterize Didymos dynamical system, internal structure and study impact results
  - Asteroid proximity operations, lander release on secondary asteroid, deep-interior analysis
  - Deep-space optical communication demonstration
- **NASA DART interceptor and Earth-based observing**
  - Measure asteroid deflection to within 10%
  - Return high resolution images of target prior to impact
  - Autonomous guidance with proportional navigation to hit center of 170 meter target body
  - Leverage space-based missile technology

Target: Didymos in 2022



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AIM payload primary objectives

- Mass: 10% accuracy
- Shape: accuracy of 1 m in height, spatial resolution of 5 m
- Binary orbital period and Dydimoon's semimajor axis: 1% accuracy
- Topography and granularity of Didymoon's surface material: resolution of 1 m globally and 10 cm locally on ~10% of the surface area
- Discrimination between bare rock and rough surfaces
- Data on mechanical properties in at least one location (goal: 3), e.g. compressive strength

AIM payload primary objectives

- Structure and layering of Dydimoon's shallow subsurface down to a few meters with a vertical resolution of 1 m (goal: 0.2 m) and 1 m in horizontal position; to map the spatial variation of the regolith texture (same resolution)
- 2-D distribution study of rocks, boulders, etc… embedded in the subsurface (same resolution)
- Derive an estimate of dielectric permittivity
- Characterize the structural homogeneity of Didymoon (discriminate between monolithic vs. rubble pile structure) and determine Didymoon's 3D structure (deep layering, etc …)

AIDA

Mutually Supporting AIDA Goals: Planetary Defense, Science, Technology

AIM

- Characterize the Didymos secondary component by analyzing its dynamical state, mass, geophysical properties, surface and subsurface structure
- Demonstrate deep-space optical communication technology and perform inter-satellite communication network with CubeSats and lander
- Deploy the MASCOT-2 lander on Didymos secondary asteroid and sound its interior structure
- [With DART] Determine the momentum transfer resulting from DART's impact by measuring the dynamical state of Didymos after the impact and imaging the resulting crater
- [With DART] Study the shallow subsurface and deep-interior structure of the secondary after the impact to characterize any change

DART

- Demonstrate asteroid deflection by kinetic impact
- Measure asteroid deflection
- [with AIM] Understand collision outcomes and validate models of the DART impact
- [with AIM] Study long term dynamics of DART impact ejecta

AIDA Summary

AIDA = DART + AIM

- Planetary Defense

Demonstrate kinetic impact mitigation technique, measure asteroid deflection

Develop and validate models for momentum transfer in asteroid impacts

- Science and Exploration

Understand asteroid collisions

Infer physical properties of asteroid surface and subsurface

Test models of binary formation

Demonstrate technologies: optical communication, cubesats, proximity operations